§4. Development of a System Code for a Helical Fusion Reactor

Goto, T. (Grad. Sch. Frontier Sci., Univ. of Tokyo), Ogawa, Y. (High Temp. Plasma Cntr., Univ. of Tokyo), Sagara, A., Imagawa, S., Yamazaki, K.

In order to realize a commercial fusion reactor, optimization of plasma performance from a broad viewpoint is indispensable. Many conceptual designs of a DEMO and a commercial reactor in tokamak system have been carried out through optimization studies through a sensitivity analysis by using simple but comprehensive system codes to take the opportunity of its symmetric nature. In the helical system, such optimization study is difficult due to the flexibility in the coil and plasma design. Helical reactors, however, have the specific feature to be inherently free from several problems by a plasma current, which may lead to the realization of the operation regime that is fundamentally different from that of tokamak. Thus the sensitivity analysis based on the inherent characteristics of helical system is quite important. We therefore have developed a simple system code for designing helical fusion reactor.

The developed system code has two main parts: the engineering design and the plasma performance evaluation. In the engineering design part, the shape of the coil is determined by a radial build scheme (see Fig.1). The consistent design is realized by using the detailed analysis results of heliotron-type reactor[1] and the stress constraint (here 300 MPa is used). The plasma performance evaluation part, the performance of the designed reactor (i.e., fusion power P_{fus}, energy confinement time τ_E, etc.) is evaluated. Here Sudo density limit[2] and ISS95 confinement scaling[3] are used. More detailed description of the system code is found in Ref.4.

In this study, we have tried to design a commercial plant. Thus we carried out a sensitivity analysis and selected design points which have minimum major radius R_0 for a given parameter set with the constraint of P_{fus}=3GW. To design a smaller reactor, the increase in fusion power density, which may cause the degradation of confinement, is needed. The calculation shows this problem can be solved by increasing the magnetic field strength B_{max}. If B_{max}>15T is achieved, confinement enhancement factor H_{ISS} falls within the range of 1.5-2.0 for most design points with aspect ratio A_p~5.0. The increase of magnetic field strength has a further favorable effect. Figure 2 shows that a high density and low temperature operation (i.e., $n_e > 4\times 10^{20}\mathrm{m}^{-3}$, T_e=8keV) is feasible if the magnetic field strength is increased to greater than 20T. While the operation density of tokamak systems are laying around $2\times 10^{20}\mathrm{m}^{-3}$ irrespective of magnetic field strength because that the density is limited due to current drive power. If density limit of $1.4\times n_{sudo}$ is allowed, this operation is possible with further lower magnetic field strength. Such increase in the magnetic field can lead the increase in the reactor weight. However, this effect can be canceled out with the weight decrease by the decrease of reactor size under relatively conservative conditions, A_p>5, β<5%, n_e<n_{sudo} and P_w< 7MW/m^2 (see Fig.3).

Consequently, we can conclude that the design of a relatively small size helical commercial reactor which has high density and low temperature operation regime is feasible with the increase in the magnetic field strength. This new operation regime is quite meaningful because it leads the reduction of heat load on the divertor. The experimental research in such new regime is also worthwhile in the viewpoint of the plasma physics study.

This work was performed with the support and under the auspices of the NIFS Collaborative Research Program NIFS (NIFS04KFDF001).

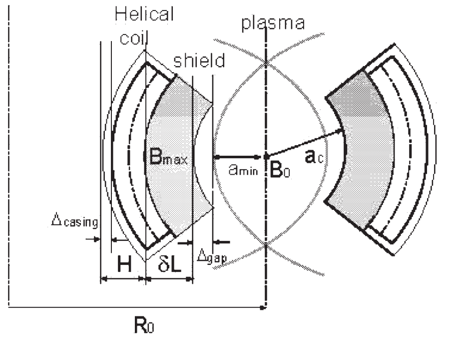

Fig. 1 Cross-section of the designed reactor

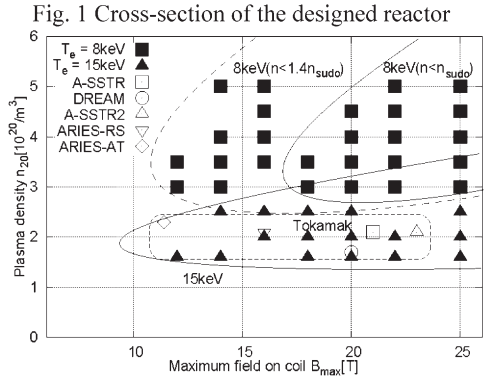

Fig. 2 Operation density n_{20} vs. magnetic field strength B_{max} for two temperature regime.

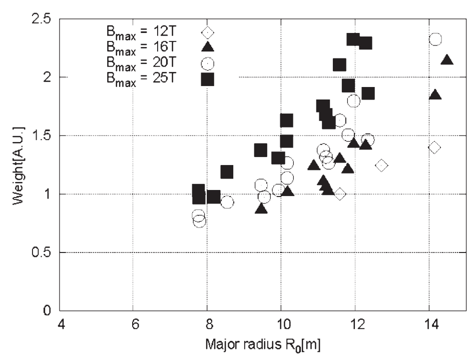

Fig. 3 Reactor weight vs. major radius R_0.

REFERENCE

(1)K., Yamazaki, et al., Fusion Technology, vol.21, 1992, pp.147-160.
(2)S., Sudo, et al., Nuclear Fusion, vol.30, 1990, pp.11-21.
(3)U., Stroth, et al., Nuclear Fusion, vol.36, 1996, pp.1063-1077.
(4)T., Goto, Y., Ogawa, Fusion Engineering and Design, vol. 81, 2006, pp.1251-1255.